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16. Abstract

Several NASA facilities are available for low gravity experimentation: the Drop Facilities at MSFC and the KC-135 at JSC. The use of these facilities allows for a rather inexpensive method of determining whether or not particular experiments will be worthwhile candidates for space experiments.

Equipment currently available include various furnaces for the Drop Tube, the Drop Tower, and the KC-135. The furnaces for the Drop Tube include both an electron beam and electromagnetic levitation furnace. A vacuum furnace is used for the Drop Tower. Several furnaces used in performing KC-135 solidfication experiments include the Automated Directional Solidification Furnace, the Isothermal Casting Furnace, the Rapid Melt/Rapid Quench and the Polymer/Video Furnaces.

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1.0 Introduction

This report covers the continuation of the Materials Processing in Low Gravity Program in which The University of Alabama in Huntsville designed, fabricated and performed various low gravity experiments in materials processing from November 7, 1990 through November 6, 1991. The facilities used in these short duration low gravity experiments include the Drop Tube at MSFC and the KC-135 aircraft at Ellington Field. In addition to the above facilities, a number of activities have been carried out at the University. In particular, the KC-135 Research Laboratory in the Research Institute Building and the UAH machine shop.

During the performance of thts contract the utilization of these ground-based low gravity facilities for materials processing experiments has been instrumental in providing the opportunity to determine the feasibility of performing a number of experiments in the microgravity of space, without the expense of a space-based experiment. In addition to the numerous experiments performed with the KC-135 furnaces developed at UAH, we have also assisted several other KC-135 experimentalist to perform their experiments during the course of this contract.

A number of periodic reports have been given to the TCOR during the course of this contract hence this final report is meant only to summarize the many activities performed and not redundantly cover materials already submitted.

2.0 Tasks Accomplished

2.1.1. In collaboration with scientists from MSFC, universities, and industry, UAH has defined, developed, and conducted materials processing experiments in low gravity using the Drop Tube at MSFC and the KC-135 aircraft at Ellington Field. This effort has included the defining of experimental equipment, and equipment, experiment-facility integration requirements, building/assembling the necessary experiment apparatus, and conducting experiments which will contribute to the knowledge base for commercialization of materials processing in low gravity. UAH has also performed the logistical support needed to execute the experimentation, and the necessary sample preparation, metallography analysis/ interpretation and and physical properties measurements of processed samples. UAH has interfaced with designated MSFC scientists and project representatives who provide Center policy, programmatic requirements and goals, priorities, and scientific and technical advice.

2.1.1 All ground based facilities have been very productive during the duration of this contract. The Drop Tube at MSFC has worked daily to perform drop experiments, build up experimental hardware for drops and provide maintenance on existing instrumentation. Dr Mike Robinson has provided the leadership for MSFC in over-seeing this facility and its function within NASA's materials processing program. Tom Rathz has led the UAH activities at the Drop Facilites and, although he works full time under the Principal Investigator for UAH, Tom has also worked quite closely with Dr. Robinson in determining and meeting scientific objectives at the Drop Facilities.

Current experimental hardware which is still being used for drop tube experiments and includes the electromagnetic levitation furnace and the electron beam furnace. We did spend considerable effort working with Dr. Taylor's Wang group at Vanderbilt University to integrate their resistive heated furnace for high T_c materials research into the Drop Tube Facility; however, that sysem never did function correctly.

2.1.2. UAH has flown KC-135 experiments on eight different missions during the contract period. Scheduling of the UAH experiments was predetermined by a master schedule generated by MSFC. Slippages due to aircraft down-times are the major reasons for any cancellations in scheduled aircraft experiments and d~ring this contract no major down-times occurred.

The primary experimental hardware which has been used for KC 135 experiments still includes the Advanced Directional Solidification Furnace (ADSF) and the Isothermal Casting Furnace (ICF). In addition UAH has assisted in the transport of an Orbital Tube Welder Experiment provided by Richard Poorman of MSFC and used by Rocketdyne personnel in the welding in Space experiment Also a Laser Welding experiment for UAH has been transported to JSC on a number of occasions. This experimental hardware was fabricated by UAH on a previous contract and is being used in preparing for proposal information to obtain funding from Code SN at NASA/Headquarters. In addition we have assisted in transporting and flying during the final portion of the contract the recently modified Rapid Melt/Rapid Quench furnace for SSL.

2.1.3. UAH is fortunate to continue with experienced personnel with no extended down times and has continued to maintain a productive capability As an example of the continued progress made in the productivity of the Drop Tube the chart below lists the number of Drop

tube experiments made at the facility during FY90 in comparison with the previous two years.

DROP TUBE PRODUCTIVITY

YEAR	1988	1989	1989	1990
TOTALS	404	315	472	450

Figure 1. Histogram from the above data showing the numbers of Drop Tube Experiments performed from 1988 - 1991.

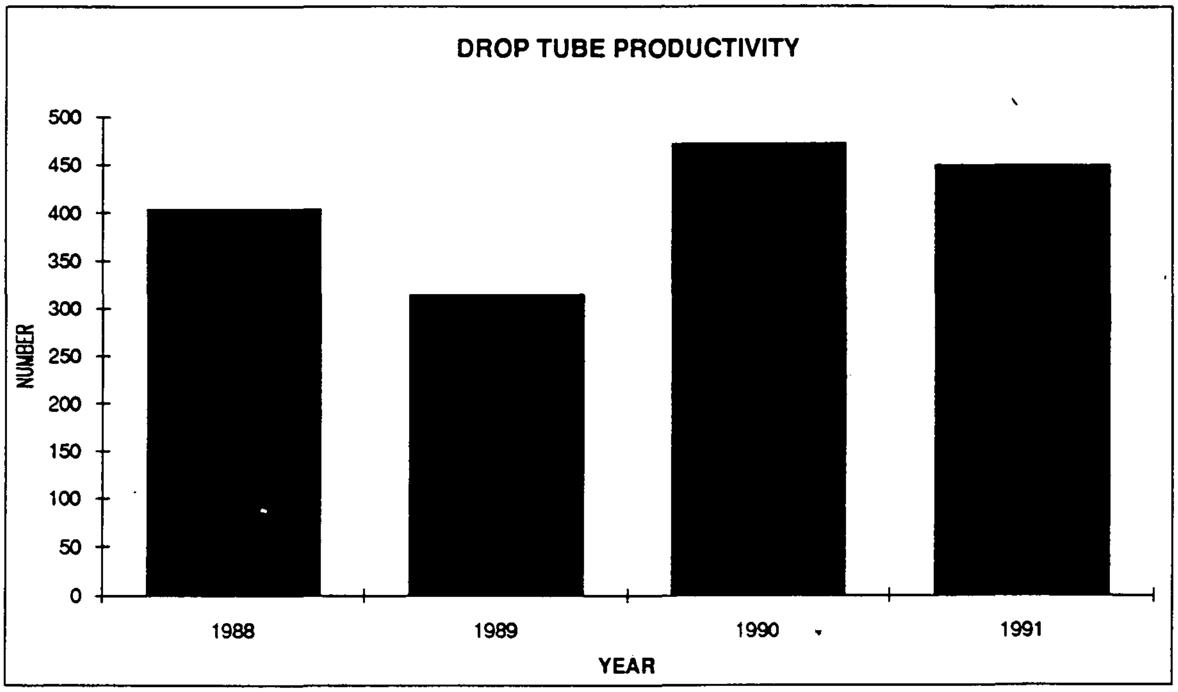


Figure 1 shows a histogram of the drop distribution from the above table. The reason for the smaller number of drops in FY89 was due to a decrease in the number requested by the Vanderbilt University group. In FY90, the primary interuptions were the use of the drop tube for a tethered satellite test in January and maintenance and set-up for the Nb drops for Dr. Mike Robinson. In addition UAH made 49 drops with AuRh in May. Dr. Barry Andrews is the Principal Investigator for that experiment.

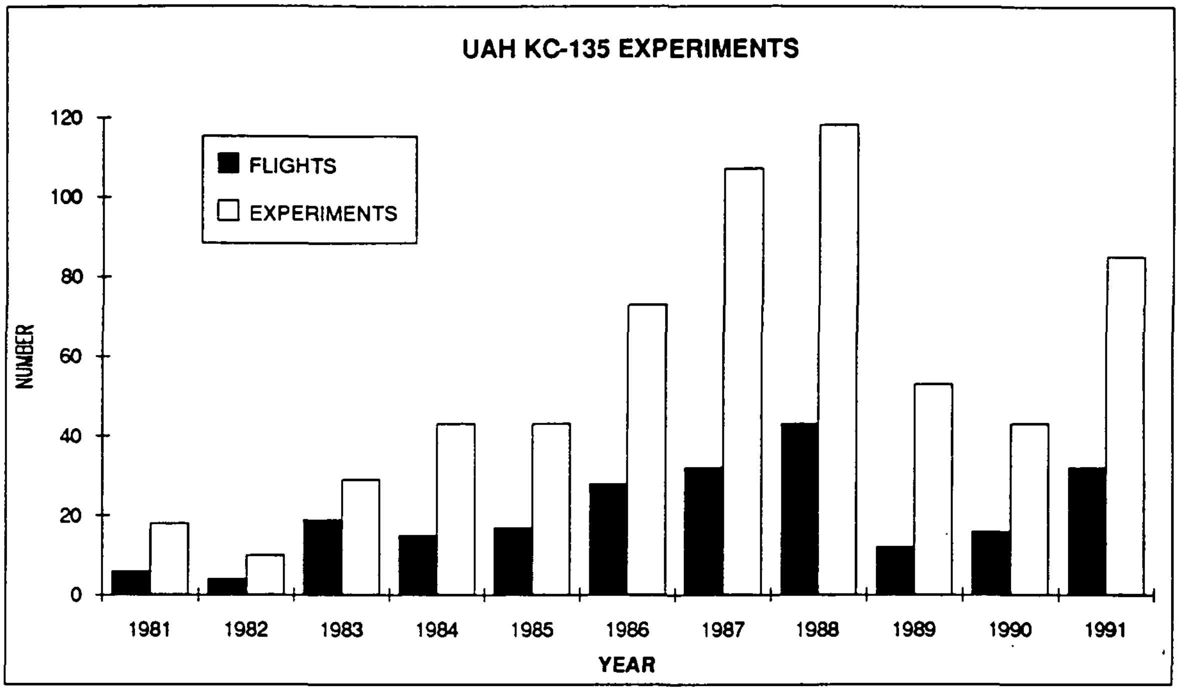
2.1.5. The KC-135 activities have also been quite active during this contract period. For this task we have been primarily concerned with experiments that have been performed with the ADSF and the ICF furnaces. Scientific investigators for these furnaces include many collaborations that Dr. Pete Curreri has established with the University of Alabama in Tuscaloosa, Rockwell International, and UAH.

Dr. Donald E. Morel for Applied Research Laboratory is the principal investigator for studying metal matrix composites. The Rapid Melt/Rapid Quench furnace was flown by our group to perform such experiments. Consequently a new twist on the ADSF this year has been Guy's modification to the ADSF to perform rapid melt/rapid quench experiments. Two series of experiments were performed with the modifcation. Several of Don Morel's samples and several of a Purdue undergraduate, Ms. Beth Stubbins were flown. Ms. Stubbins samples were tin/zinc carbonate foam metal experiment that was the winner in a contest sponsored by the National Space Club. Both experiments proved to be successes for the ADSF experiment. Guy also flew on a Payload Systems flight in March of this year to perform the experiments for Ms. Stubbins. JSC transferred funds over to the KC-135 program to assist in the payment for the flight hours. The funds for Guy's travel to perform the experiments came out of our budget.

However, the ADSF modifcation still does not completely replace the RM /RQ. Its overall capability, particularly in temperature range is still preferred. A chart showing the number of flights and experiments performed by UAH since 1981 has been generated for this report. It is shown below.

It is interesting to note that the number of experiments performed on the KC-135 by UAH were highest when the Shuttle was not flying and lowest when the KC-135 was grounded for mechanical problems. Although over the years a large number of experiments have been performed, we feel that the total number of experimenters who want to use the KC-135 as a low gravity testbed may be decreasing due to lack of information about how to perform and interpret an experiment using the aircraft facility.

Figure 2. Chart showing the number of flights and experiments performed on the KC-135 by UAH since 1981.



The lack of a large number of experiments suggests that results from these types of experiments may not be as easily understood in terms of what goals are set for KC- 135 experiments. For instance if an experimenter anticipated the type of data obtained is a space-based experiment or if he under-estimates the work required to interpret the directional solidification results properly, then the utility of the KC-135 as an experimental platform may be received negatively. perhaps this indicates that the program should provide a better understanding of what experimental results can be achieved in the KC-135 environment. To help meet that end, Dr. Kaukler and I have developed a video convective flow analyzer to determine what fluid fiows mechanisms do exist as the KC-135 flies parabolic manuevers.The report from that work will be published and hopefully will give some guidance to the usefulness of the KC-135 as a low gravity testbed.

2.2.0 UAH has developed procedures delineating the objectives, test sequences, operational timeline, etc. prior to each experiment or experiment series, This has included ground-based checkout of experiment apparatus and support systems, both for pre-flight, flight and ground control, and installing and testing suitable apparatus in the facilities in order to provide the

appropriate processing conditions required for the experimental work. UAH has recorded and analyzed experiment apparatus operation parameters and thermal profiles as appropriate to intepret results of the experiments during the contract period. Existing apparatus such as E-beam furnaces, dropper fumaces, and levitation devices have been made available to any experimenter wishing to use the Drop Tube on an "as available" basis. Scheduling of apparatus and facilities has been done through the designated MSFC coordinator, Dr. Mchael Robinson of SSL.

2.2.1. UAH personnel have continued to work on performing tests and check-outs on all facilities as part of the facilities requirements. The Drop Facilities need extensive mechanical and electrical preventative maintenance, which UAH is not authorized to perform. SSL does provide technician support for this activity. This arrangement works well, since the technician can interface more easily with MSFC facilities and supply personnel than the University personnel can.

2.3. Where required UAH has formulated written scientific and/or engineering reports for each experiment and/or experiment series. These reports were augmented with metallurgical reports, where appropriate and were provided on a timely basis for internal program use. No reports or publications intended for distributions to other organizations or individuals included data furnished to NASA with restrictive legends by third parties.

2.3.1. After the experiments were performed, each scientific investigator for each facility or experiment received their samples, the data derived from each experiment, and any additional comments which might assist in the interpretation of the experiment. For the Drop Tube this data set include pyrometer data, pressure measurements and electrical parameters effecting the molten droplet. For the KC- 135 experiments the data includes strip charts and computer data files with temperature, acceleration, and position of sample.

A useful experiment conducted during this contract in which accelerometer data was collected from several different flight profiles, i.e. good weather and poor weather conditions. This document was submitted to Dr. Peter Curreri for inclusion into a TM publication editted by him. UAH has provided consultation, expert interpretation of experiment results of metallurgical and chemical processes, expert analysis and interpretation of optical records taken during low gravity experiments, and recommendations for research tasks being conducted under this contract.

2.4.1 This activity has in general been performed upon request from other groups using or wishing to use the ground-based facilities. Both Guy Smith for the KC-135 operations and Tom Rathz for the Drop Facilities have responded to numerous requests about paritcular features of performing experiments in those facilities. Dr William Kaukler has also assisted in responding to outside requests for information about use of the facilities or general information about experimentation in low gravity. In addition, we have received many visiting groups at the Drop Facilities which have been escorted through by Public Affairs Office at MSFC.

Guy Smith has provided some expert advise in the fabrication of furnace to a number of groups who are building furnaces. His expertise has developed over the years and it continues to be beneficial to the NASA Low Gravity program in a number of different ways. He has also been able to train student workers in the art of winding the furnace cores such that we are able to provide assistance when needed. We have also received a number of microgravity experimentalists who have visited our laboratory at UAH to see the KC-135 experimental hardware.

2.4.2. In general other than tour groups visiting the Drop Facilities and the UAH laboratory, we have not been requested by too many outside groups to provide expertise on low gravity materials processing. Due to the nature and the diversity of the many experiments we perform at the various facilities, we feel that we should be more beneficial to the program than we currently have. An accumulation of knowledge from building many experimental packages at the various facilities is certainly useful in designing a scientific experiment for space, that would benefit from preliminary experiments at any of the ground-based facilities. It would appear from our perspective that the many programs initiated by NASA for new hardware do not seem to follow a master plan. If such a plan existed it would certainly make it easier for groups such as ours to make inputs into the role that the ground-based facilities can play in the various materials processing programs.

A major contribution to both the electromagnetic levitation work and the electron beam work may arise through computational modeling capabilites currently being devised with a commercial software package called Maxwell. It is a finite-element program developed by Ansoft. Another new software package which we used for the video convective flow modeling is the finite difference program called Easyflow. It also allows one to simulate the effects of gravity on fluid flow phenomena.

2.4.3 Task 2.5, as stated below actually prohibits us from making presentations at technical conferences concerning any scientific work being performed at the facilities without the scientific investigator being involved. In order not to show any indication of bias by being part of some experiments that we make at the facilities, we have not made a substantial effort to become part of a particular research team. Therefore we are basically open with everyone However. as part of a university research organization, we are often requested to write more refereed publications. Consequently we are frequently encouraged to find ways to publish without violating the philosophy of Task 2.5. We are currently working on ideas to fulfil these needs They would certainly be beneficial to the overall objectives of the program

2.5. UAH has maintained procedures to protect propriety and trade secret data provided by an industrial organization from unauthorized disclosure.

2.5.1. UAH has performed this task accordingly by not publishing or sending anyone's data to anyone other than the scientific investigator himself. The TCOR, in this case Dr. Robinson, is always consulted before sending out any information which is not already in the public domain. We have made general presentations about Materials processing in Low Gravity, but only used information currently open to the public or already published Dr Mike Robinson serves as the official who determine what information can be transmitted. A concern of mine, of which the philosophy of this task basically helps to propagate, is that officially we are authorized only to transmit the data and the samples to the scientific investigator. We have no mechanism for the investigators to share with us the results of the experiments. Unfortunately this information would be useful for the purpose of maintaining optimal control of the experimental parameters and hardware. Since we do not in general get feedback from the scientific investigators about their scientific results we are quite limited in determining if our experiments are really what the investigator wanted Thus this feedback could be used to determine any future modifications or experimental changes required to optimize upon particular experiments.

2.6 UAH has conducted various experimental drops, as directed, associated with operational readiness demonstrations of the drop tube facility and scientific investigations.

2.7 Since the recording of droplet temperatures as a function of drop time in the Drop Tube is such an important part of most Drop Tube experiments, it is necessary to continue to search for and evaluate for the most cost effective method for determining transit droplet temperature along the length of the Drop Tube in order to make recommendations for

implementation of such a method or methods. Upon specific direction procure, install and verify equipment and/or instrument required to implement the preferred method.

2.7.1 This problem has a long standing thmst in materials processing experiments in low gravity. Non-contact temperature measurement is required to understand solidification phenomena, fluid behavior, etc in containerless environments. The most progress has occurred since Tom Rathz has been in charge of the facility and Boyd Shelton was hired to respond to electronic instrumentation requirements at the Drop Facilities. Since Boyd left to take a job in Africa, we have not has a good instrumentation person at the drop tube.

2.7.2. Over the years additional work and analysis have been performed by members of our group, Tom Rathz and Dr. William Kaukler and by others such as Dr William Hofmeister of Vanderbilt University. Alternatives included high gain Si detectors, temperature stabilized Si detector and logarithmic amplifiers. Boyd Shelton has continued to work with improving the capability of the Si detector system, performing experiments in parallel with other activities at the Drop Facilities. Recently believe that this method will perform adequately for the tasks at hand when fully optimized. Tom Rathz has continued developement of quartz light-pipes at the Drop Tube, thereby increasing the quantity of radiance from recalescence collected by the detectors. They see noticeable improvements in the S/N level of these signals.

2.7.3 Tom Rathz has been able to participate to some extent with the Non-contact Temperature Measurement Working Group. Thus he is able to at least keep abreast of other techniques which are being considered in NASA's various programs.

2.8. Upgrade Drop Tube and Drop Tower experiment apparatus capability through continual evaluation of experiment and operational requirements.

2.8.1. In uddition to the detectors required for temperature measurement of falling drops, UAH personnel have made a number of improvements to increase the productivity of the Tube and improve upon the data collection process for the facilities. Continual up-grading of the High Speed Data Acquisition systems includes a Nicolet Transient Digitizer, which is interfaced to the silicon detectors along the tube. In addition we have maintained the video capability to observe samples during the sample heating and melting periods in the belljar. These systems are still working quite well. We are also still using an optical disk for archiving drop tube data. A number of modifications have been made to improve upon the ease of sample changing in both the belljar and the catch tube. These modifications have

been instrumental in improving control of samples during processing and quicker turn-around time in running experiments.

2.9. Modify, as required, the drop tube experiment packages associated with MSFC approved experiments and conduct drops as necessary to support the investigation. Continuous improvement in the operational characteristics of both facilities has occurred. For instance the Drop Tube has improved the vacuum attainable by increasing the number of pumps, improvement in temperature measurements with both a new optical pyrometer and new detectors, and evolving redesigns in sample holders and retrieval systems. Also notable in terms of determining recalescence in undercooled samples is the addition of a video camera looking up the tube from the bottom. If recalescence does occur, it is captured on the video tape for comparison with the data from the Si detectors. Some discussion has occurred with respect to using this data for temperature deteterminations during the drops; however, the complexity of the task makes it less desirable than using the Si detectors at this time. With improvements in CCD's and imaging systems in the future, we may reconsider this capability again.

2.10. Analyze experimental results and prepare reports.

During the course of the contract we have analyzed all experimental results and submitted samples to the scientific investigator as requested. Reports of these experiments have been prepared and submitted to the appropriate parties also.

2.11. Conduct special studies to define new experiments to be perfomed on the KC-135 aircraft and establish the requirements for the equipment to be used to carry out the experiments.

2.11.1. Guy Smith and his staff have also continued to work on the construction of a three-zone ADSF for the KC-135 experiments in parallel with all the other activities being performed for KC-135 experiments. It was not be ready for flight durng this contract period. The completion time for this appartus is not predictable due to the unknown funding levels for KC-135 experiments in the future.

The major problem facing KC-135 furnace activity is that all furnaces certainly will not be able to fly at the same time. Assuming the video furnace and the Rapid Melt/Rapid Quench are made flight ready and the three-zone ADSF is operational, there will have to be some scheduling worked out to optimize the use of all the furnace capability for the aircraft. Due

to power limitations and the problem of long soak times affecting the number of parabolas obtained during a mission, only one or two furnaces can really ever fly at the same time. In addition, there is the continuing problem of the new hardware being transported to Ellington getting larger and heavier, thereby making transportation more difficult. With sufficient planning there would be more optimal control for implementation of all the furnaces. Mr. Jeff Mullins, the MSFC coordinator, has taken charge of this problem and is working to achieve the optimal arrangements very nicely.

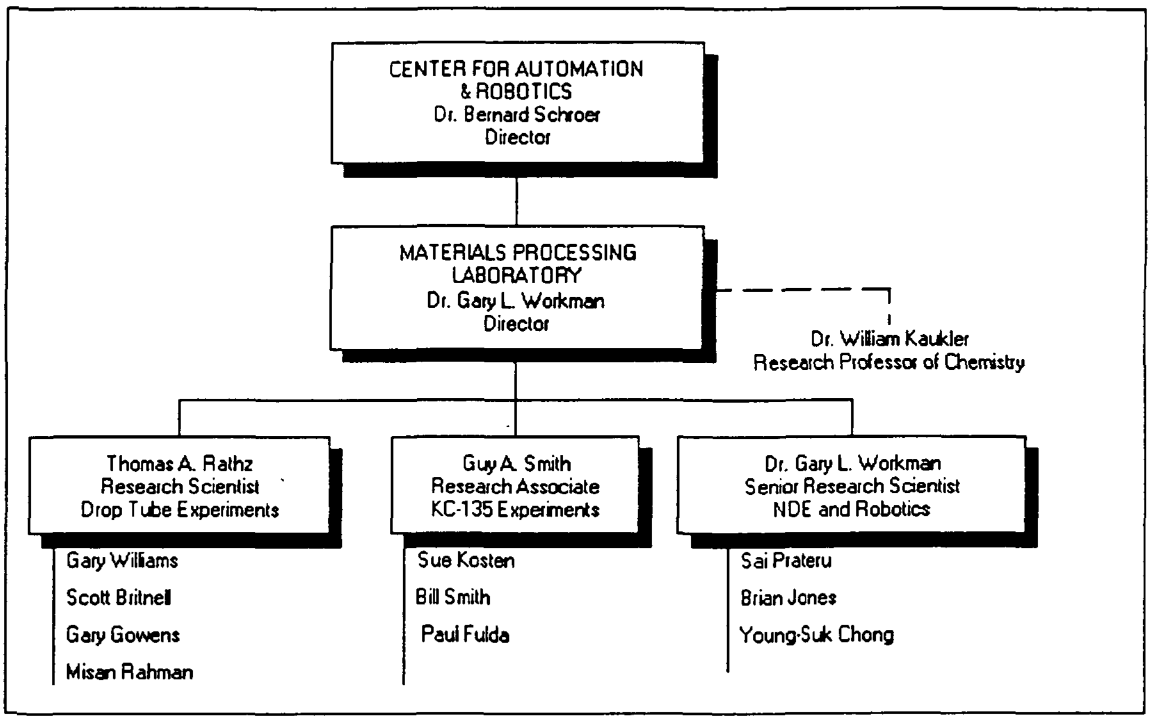
2.11.2. Additional activities which have supported other experiments flying on the KC-135 include assistance with the Rapid/Melt Rapid Quench Furnaces and making temperature measurements for the Orbital Tube Welder of Richard Poorman of MSFC. All of these activities were partially supported to cover additonal hardware and for travel expenses caused by their implementation.

2.12. Set optical pyrometer calibration test facility to include calibration, and associated equipment necessary to insure drop tube optical pyrometer calibration.

We have continued working on this task through several generations of equipment. Tom Rathz has reached a fairly high level of consistency with the current quartz optical waveguides and silicon detector arrangement. In addition, as mentioned earlier, the Nicolet transient analyzer has worked well in capturing the fast signals from the detectors.

3.0 Personnel

The following chart, Figure 3, shows the organization chart for the Materials Processing Laboratory in the newly formed Center for Automation and Robotics. The Materials Processing Laboratory has basically evolved over the years to meet the needs of this program and to better respond to future needs of microgravity materials processing programs. You will notice that during the year, October 1, 1991; the group effectively left the Johson Research Center and moved into the Center for Automation and Robotics. This Center reports directly to Dr. Kenneth Harwell, Vice-President for Reserch and Graduate Studies at UAH.



3.0. Acknowledgements

The work performed on this contract was successful due to the fact that many people were able to provide help and assistance in meeting the above goals. This includes Dr. Mike Robinson as TCOR for the contract and coordinator for the Drop Tube, Mr. Jeff Mullins, NASA/MSFC and Mr. Robert Williams and Ms. Linda White, NASA/JSC in the KC-135 program, and Kevin Vellacott-Ford at the Drop Facilities, and of course, the many UAH

personnel who have worked with each of the facilities reported here as listed in the organization chart above.